RENEWABLE ENERGIES

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PRACTICAL CLASSES

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III 2.A WIND RESOURCE EVALUATION USING IN-SITU AND DOPPLER LIDAR WIND MEASUREMENTS

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A. MAIN QUESTIONS TO BE ADRESSED DURING THE TUTORIAL

The main issues that will be addressed during the tutorial are:

1. At a given geographical location, how can we evaluate the wind energy?
2. What is the order of magnitude of wind power resource at SIRTA observatory?
3. What parameters can alter the theoretical potential of wind energy production?
4. How can we optimize and manage renewable energy production?
5. Considering your various academic backgrounds, what would you suggest to satisfy the total energy demand with renewable energy in 40 years?

B. CONTEXT AND ISSUES

Climate concerns and dwindling fossil fuel resources are driving an increasing demand for renewable energy solutions. Many countries have passed legislation to increase the use of renewable energy sources and this has, in turn, created a market for new technologies in the area.

Energy sources that are perpetual, or self-renewing, guarantee a secure supply, thus minimizing dependency on outside energy suppliers. At the same time, use of renewable energy may cut emissions of carbon dioxide, thereby addressing environmental concerns. Wind turbines have continued to grow in size and efficiency, from 50 kW in the late 1980s to up to 5 MW today.

Wind power is intrinsically CO_2 free. Therefore, wind turbines are rapidly becoming an integrated part of modern power production in many countries. The industry now produces wind turbines that play an active part in the control and regulatory functions of power systems, in contrast to older turbines that did little to support the stability of the grid.

The future R&D challenges for the industry, will focus on optimizing wind turbine performance by designing the most efficient and robust wind turbines while reducing the weight and, if possible, physical size of the turbines. The top five global producers of wind energy in 2009 were Germany, the United States, India, Spain, and the United Kingdom. These days, wind power is predominantly used to produce electricity using turbines. Most of these turbines are oriented on an horizontal axis and are shaped like airplane propeller.

C. TUTORIAL OBJECTIVES AND ORGANIZATION

SIRTA Observatory is composed of 3 zones (Z1, Z2 and Z4, see annexe document) with multiple instruments to collect the wind characteristics at different altitude. These active or in-situ instruments monitor the wind speed (m/s) and wind direction (°) between the surface and ~2500m high. Here, we are going to focus our study between the surface and 200m high, i.e ranges concerned by the wind turbine, where the surface properties (trees, buildings) can significantly modulate the wind speed. Wind speed is going to be compared at regional scale and wind power is going to be estimated.

Data available for this tutorial are:

(1) Wind speed and direction at SIRTA site for the 3 zones and for several altitude for the 15 Jan. – 15 Feb. 2010 period

(2) Wind speed and direction at SIRTA and at 3 regional sites for Jan. to Dec. 2008.

Experiment

1. Observe how wind speed and direction are measured at SIRTA site. Pros and cons of each instrument (range, cost, accuracy, method of calculation)
   - See annexe document for wind lidar
   - Which differences between the multiple zones at SIRTA site?

Wind resource at SIRTA site: Measurement and statistics

1. Plot the time series of horizontal wind speed between the ground and 200m AGL[1] in zone 1 for the period 15-22 January 2010 (Figure 1).
2. Plot the vertical distribution of the average horizontal wind speed between 1 and 200 m in zone 1 (Figure 2).
   - Calculate the average wind speed for each altitude (see Table 1)? Conclude on the influence of the altitude on wind speed. What can be the effect of the surface friction?
3. Plot the time series of the wind speed and wind direction at 10m in zone 1 (LMD[2] mast), 10m in zone 4 and 10 m in zone 1 (IPGP[3] mast) for the period 15-19 January 2010 (Figure 3).
4. Plot the vertical distribution of the average horizontal wind speed for the different locations between 15 and 31 January 2010 (Figure 4).
   - What are the main differences between each time series (trees, building, etc.)? Minimum, maximum?
   - Which impact on wind speed? Calculate the average, the standard deviation of wind speed for each location (see Table 1)? Conclude.
5. Plot the time series of the vertical wind speed between 40 and 140m for the period 15-19 January 2010 (Figure 5).
   - Calculate the average, the standard deviation of wind speed for each altitude (see Table 3)? Which impact of the altitude?
   - What is the order of magnitude compared to horizontal wind speed? Conclude.

Wind resource at regional scale: variability of wind speed and direction

1. Plot the time series of the wind speed at regional scale (average of Roissy, Orly, Paris-Montsouris and SIRTA site) for the year 2008 (Figure 6).
   - What is the yearly average wind speed for each site (Table4)? Maximum and minimum wind speed?

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[1] AGL : Above Ground Level

[2] LMD : Laboratoire de Météorologie Dynamique (http://www.lmd.jussieu.fr/)

[3] IPGP : Institut de Physique du Globe de Paris (http://www.ipgp.fr/)

- What is the number of days/hours with an average wind speed stronger than 2, 4, 6 and 8 m/s?

2. Plot the time series of the wind speed (daily and monthly average) for the 4 sites during the year 2008 (Figure 7).
   - What is the annual average wind speed for each site (Table 5)? The maximum difference?
   - Is SIRTA site representative of the wind speed at the regional scale?
3. Plot the wind speed distribution for each wind direction North-South-East-West (Figure 8)
   - Is there a main direction for the maximum wind speed? Why?

After Lunch

Effective wind energy at regional scale

1. The wind power produced by a wind turbine is defined as *Equation 1*

$$\overline{P} = \frac{1}{2}\overline{\rho} S C_p \overline{u}^3 K_e \qquad \textit{Equation 1}$$

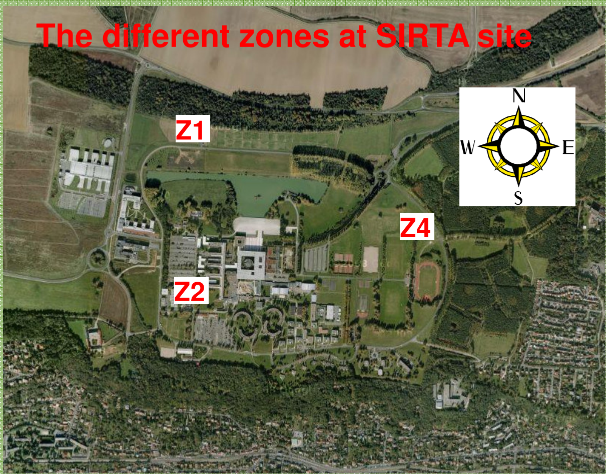
Where, C_p is the aerodynamic yield, ρ the volume mass of atmosphere kg/m^3, u the wind speed in m/s, S is the wind turbine area in m^2.
Plot the time series of the daily K_e coefficient between 15 Jan. and 15 Feb. 2010 (Figure10). Consider 10m, 60m and 200m AGL.
   - What is the range of variability for each altitude? The average value of K_e (Table 6)?
   - What represents this coefficient? Impact for the wind power at the different altitudes?
2. Plot the time series of the wind power at 10m AGL for daily and monthly averages at Roissy, Orly, Paris-Montsouris and SIRTA sites in 2008 (Figure 11). Consider that $C_p = 0.3$, $\rho = 1.225$ kg/m^3, $S = 12$m^2 and u is the wind speed measured at 10m AGL over each site.
   - What is the average K_e coefficient and wind power for each site (Table 7)? Difference? Why?
   - What is the best site for a 10m high wind turbine?
3. Plot the time series of the wind power for 10min measurements at 60, 80, 120 and 200m at SIRTA sites between 15 Jan. and 15 Feb. 2010 (Figure 12). We consider wind turbine with 25m, 35m, 55m and 95m of diameter respectively.
   - What is the average wind power at these 4 altitudes (Table 8)?
   - Difference? Optimal altitude? Why?

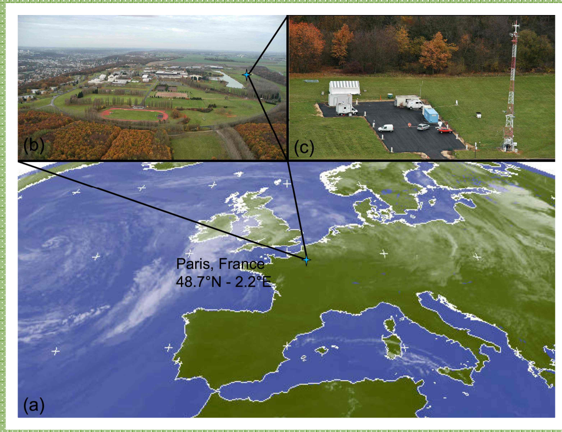
D. SOME REFERENCES

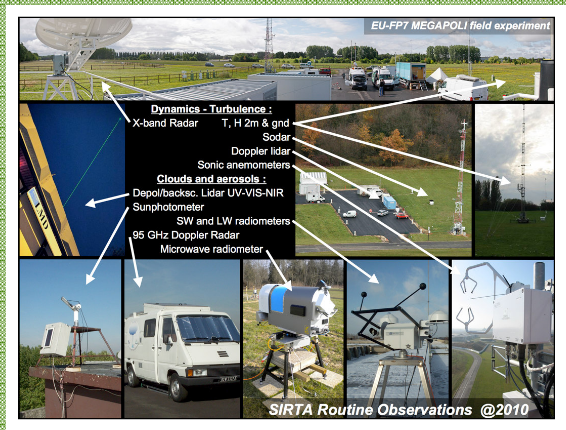
http://www.leosphere.com/
http://www.edf.fr/the-edf-offers/edf-fr-home-200420.html#Home
http://www.talentfactory.dk/en/core.htm
http://sirta.ipsl.polytechnique.fr/

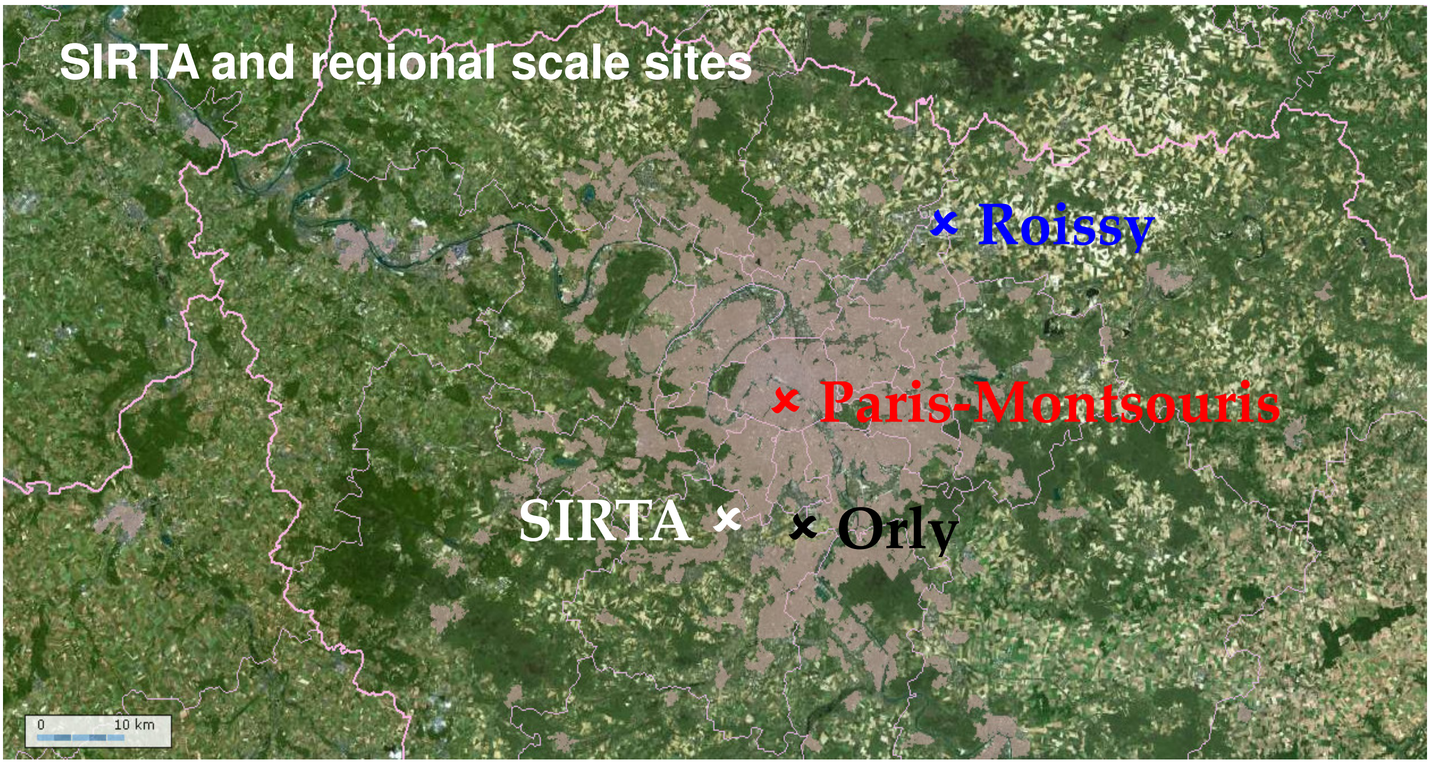
The SIRTA Facility

Science objectives: study macro and micro-physical properties of clouds and aerosols (vertical distributions, occurrences, particle shapes and sizes), the dynamics of the atmosphere (boundary layer and free troposphere) associated with their life cycle, and their impact on the radiation budget and photochemistry, exploiting both active and passive remote sensing and multi-spectral synergies.









SIRTA

Site Instrumental de Recherche par Télédétection Atmosphérique

Wind lidar WLS70

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Specifications

MEASUREMENTS

Range	40m to 200m
Data sampling rate	1s
Number of programmable heights	10
Speed accuracy	0,1m/s
Speed range	0 to +60m/s
Direction accuracy	2°

ELECTRICAL

Power supply	18-32V DC / 100 to 230 VAC 50-60 Hz
Power consumption	45W

ENVIRONMENTAL

Temperature range	-30°C to +45°C / -22 °F to 108°F
Operating humidity	0 ... 100 %RH (non condensing)
Housing classification	IP67
Shocks & vibration	ISTA / FEDEX 6A
Safety	Class 1M IEC/EN 60825-1
Compliance	CE

TRANSPORTATION

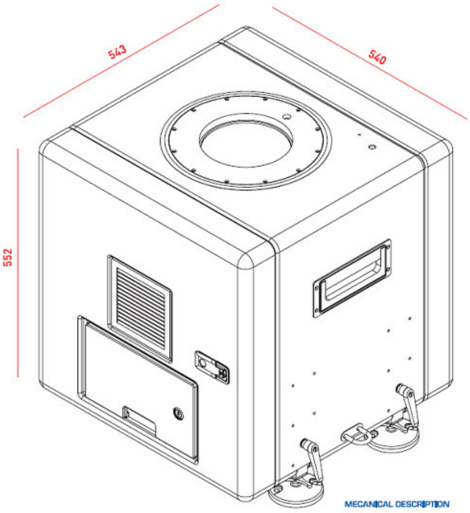
Size	System : 543 x 552 x 540mm Transport case : 685x745x685mm
Weight	System : 45 kg Transport case : 21 kg

SOFTWARE/DATA

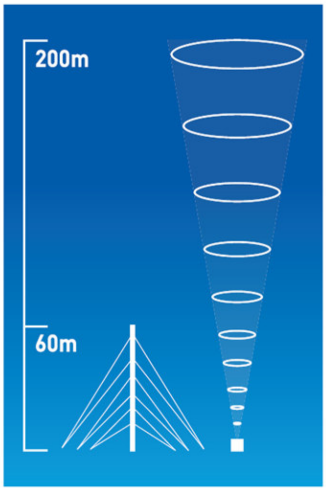
Data format	ASCII
Data storage	SSD and compact flash (backup storage)
Data transfer	LAN/USB
Standard WINDSOFT™ Software	Configuration & control real time display diagnostic
Output data	1s/10min Horizontal & vertical wind speed min & max, direction, SNR Quality factor (data availability) GPS coordinates

http://www.leosphere.com

The wind lidar installed at SIRTA site is produced by Leosphere society. It is an active remote sensor based on light detection and ranging tecehnique. Wind lidar relies on the measurement of Doppler shifted laser light backscattered by particles in the atmosphere (dust, aerosols). Lidar is the only remote sensor technology to measure the absolute speed of the wind.

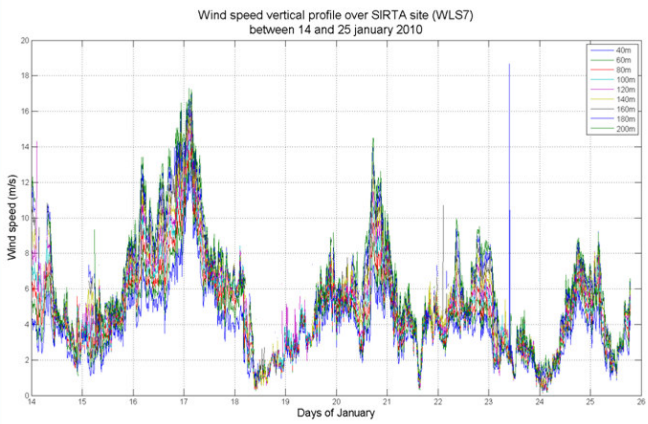


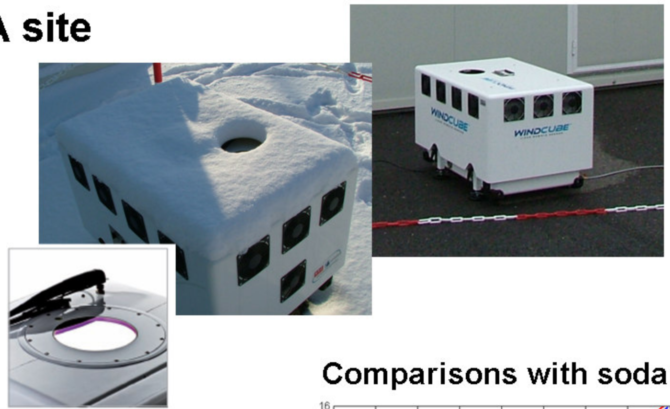
MECANICAL DESCRIPTION

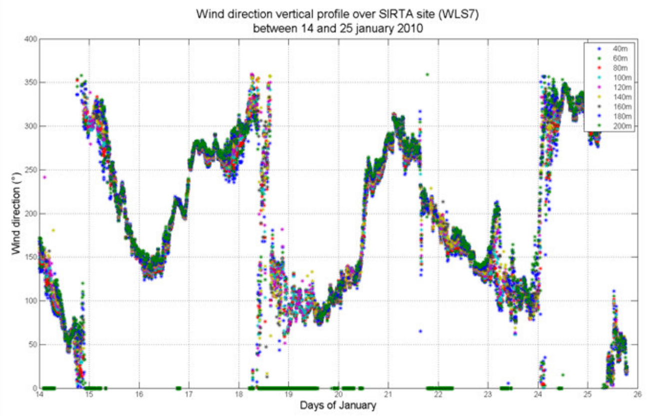


10 HEIGHT WIND PROFILE IN 1 SECOND

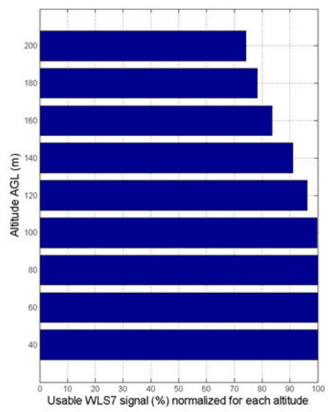
Example of measurements at SIRTA site







Vertical sampling



Comparisons with sodar